IV. HABITAT NECESSARY FOR SURVIVAL

Adults

Migration

Coho salmon usually immigrate during late summer and fall and their behavior may have evolved in response to particular flow conditions. For example, obstructions that may be passable under higher discharges may be insurmountable during low flows. Conversely, early-running stocks are thought to have developed because those coho salmon could surmount obstacles during low or moderate flows but not during high flows. If flow conditions in a stream are unsuitable, the fish will often mill about the vicinity of the stream mouth, sometimes waiting weeks or even, in the case of early-run fish, months for conditions to change (Sandercock 1991). Although substantially greater depth may be needed to negotiate barriers, preferred average depth to allow passage of coho salmon is approximately 7.1 in. (Bjorn and Reiser 1991).

Reiser and Bjornn (1979) indicate that migration normally occurs when water temperature is in the 45^0 to 61^0 F range. Excessively high temperature may result in delays in migration (Monan et al, 1975). Additionally, excessively high temperature during migration may cause outbreaks of disease (Spence et al. 1996) and may reduce the viability of ova (Leitritz and Lewis 1980).

The high energy expenditures of sustained upstream swimming by salmonids require adequate concentrations of DO (Davis et al. 1963). Supersaturation of dissolved gases (especially nitrogen) has been found to cause gas bubble disease in migrating salmonids (Ebel and Raymond 1976).

Reid (1998) found that high turbidity affects all life stages of coho salmon. In the case of adults, high concentrations of suspended sediment may delay or divert spawning runs (Mortensen et al. 1976). As an example of a response to a catastrophic event, coho salmon strayed from the highly impacted Toutle River to nearby streams for the first two years following the eruption of Mount St. Helens, Washington (Quinn and Fresh 1984). Salmonids were found to hold rather than migrate in a stream where the suspended sediment load reached 4,000 mg/L (Bell 1986).

Migrating coho salmon require deep and frequent pools for resting and to escape from shallow riffles where they are susceptible to predation. Deep pools are also necessary for fish to attain swimming speed necessary to leap over obstacles. Pool depth needs to be one-and-one-quarter times the height of the jump for adult fish to attain the necessary velocity for leaping (Flosi et al. 1998)

LWD and other natural structures such as large boulders provide hydraulic complexity and pool habitat. LWD also facilitates temperature stratification and the development of thermal refugia by isolating pockets of cold water (Bilby 1984; Nielsen et al. 1994). Riparian vegetation and undercut banks provide cover from terrestrial predators in shallow reaches.

Spawning

Coho salmon spawn mostly in small streams where the flow is 2.9 - 3.4 cfs and the stream depth ranges between 3.94 and 13.78 inches, depending on the velocity (Gribanov 1948;

Briggs 1953; Thompson 1972; Bovee 1978; Li et al. 1979). On the spawning grounds, they seek out sites of groundwater seepage and favor areas where the stream velocity is 0.98 - 1.8 ft/s. They also prefer areas of upwelling. Upwelling increases circulation of water through redds, which helps eliminate wastes and prevents sediments from filling in the interstices of the spawning gravel. The female generally selects a redd site at the tail-out of a pool or head of a riffle area where there is good circulation of oxygenated water through the gravel.

About 85% of redds occur in areas where the substrate is comprised of gravel of 15cm diameter or smaller. In situations where there is mud or fine sand in the nest site, it is removed during the digging process. However, there must be sufficient appropriate-sized gravel and minimal fine sediments to ensure adequate intersticial space for egg survival. The depth at which coho salmon deposit their eggs within the substrate is critical to incubation success. Eggs deposited within a zone of scour and fill can wash downstream. Bedload and bank stability, aided by LWD and upslope integrity, can minimize that risk. A pair of spawning coho salmon requires about 125.9 ft^2 for redd and inter-redd space. LWD and other structures such as large boulders provide streambank support, which over time helps to meter out sediment resulting from bank failure, thus decreasing large sediment input to redds. LWD also diversifies flows, reducing stream energy directed towards redds (Naiman et al. 1992). Pockets of relatively stable gravels help protect redds from the scouring effects of high flows.

Juveniles

Eggs and Larvae Incubation

Low winter flows can result in dessication of redds or may expose eggs to freezing temperatures. High water flows can disrupt and mobilize redd gravel, resulting in eggs being dislodged, swept downstream, and lost. Winter storms often cause excessive siltation that can smother eggs and inhibit intergravel movement of alevins. The associated silt load of these storms can reduce water circulation in the gravel to the point where low oxygen levels become critical or lethal.

According to Bjornn and Reiser (1991), the optimum temperature for coho salmon egg incubation has been found to be between 40 to 55 ^oF. Coho salmon embryos sustained 50% mortality at temperatures above 56.3 ^oF (Beacham and Murray 1990). Because of the tight coupling of temperature and developmental processes, changes in thermal regime, even when well-within the physiological tolerable range for the species, can have significant effects on development time (and hence emergence timing), as well as on the size of emerging fry.

A high proportion of fines in the gravel effectively reduces the DO levels and results in smaller emergent fry. Embryos and alevins need high levels of oxygen to survive (Shirazi and Seim 1981), and Phillips and Campbell (1961) suggest that DO levels must average greater than 8.0 mg/L for embryos and alevins to survive well. Eggs require gravels that have low concentrations of fine sediments and organic material for successful incubation. Bedload or suspended materials deposited on spawning redds may clog intersticial space and diminish intragravel flows, thus suffocating the eggs. Excessive sediment deposition may also act as a barrier to fry emergence (Cooper 1959). McHenry et al. (1994) found that when sediment particles smaller than 0.85mm made up more than 13% of the total sediment, it resulted in intragravel mortality for coho salmon embryos because of oxygen stress. Cederholm et al. (1981) found that in the Clearwater River in Washington, the survival of salmonid eggs to emergence was inversely correlated with percent fines, when the proportion of fines exceeded the natural level of 10 percent. Tagart (1984) found that if sediment composition included a high concentration (up to 50%) of fine sediment and sand (<0.85mm), survival was lower.

Shade provided by tall and/or mature vegetation is an important temperature regulator. LWD and other structures such as large boulders provide streambank support which, over time, help to meter out sediment resulting from bank failure, thus decreasing large sediment input to gravels.

Fry Emergence

Recently emerged coho salmon fry prefer shallow water, which leaves them vulnerable to floods that can displace them downstream into unsuitable habitat. This problem is greatly exacerbated in streams having little complexity due to lack of in-channel LWD. Displacement downstream may lead to early migration toward the estuary, and fry are poorly equipped to survive early emigration into salt water.

After emergence, fry continue to hide in gravel and under large stones during daylight hours, and within a few days they will progress to swimming close to the banks, taking advantage of available cover. They congregate in quiet backwaters, side channels, and small creeks, especially in shady areas with overhanging branches. Fry are found in both pool and riffles, but they are best adapted to holding in pools. Cold, deep, complex pools are optimum for coho salmon rearing provided there is enough dark habitat conditions and streamside vegetation for shading. Large wood and associated pool habitats provide cover from predators and refugia during high flow events (Everest et al. 1985).

Rearing

The amount of physical space available to juveniles for rearing is directly related to stream discharges (Everest et al. 1985). Lloyd et al. (1987) found that juveniles avoided chronically turbid streams, although they appear to be little affected by short transitory episodes (Sorenson et al. 1977). Published data suggest that feeding efficiency of juvenile coho salmon drops by 45% at a turbidity of 100 NTU (Reid 1998). Coho salmon rarely feed on non-moving food or from the bottom, preferring to select food in suspension or on the surface. At the yearling stage, they may become piscivorous, supplementing their insect diet with the fry of their own or other species.

By late summer and early fall, juvenile coho salmon feeding activity decreases and the fish move into deeper pools, especially those with overhanging logs and dense overhanging sidestream vegetation. Coho prefer side pools with cover instead of pools without cover. Juveniles spend more time hiding under the cover of logs, exposed tree roots, and undercut banks. Lack of adequate pools and side channels make them more susceptible to predation. By seeking cover and entering side channels, the fish avoid being swept out of the stream during winter high flows and they also avoid some predators at a time when their swimming ability is reduced because of lowered metabolic rate.

Salmonid strategies for coping with high turbidity include use of off-channel and clean-water refugia and temporarily holding at clean-water tributary mouths. These coping strategies are partially defeated by sediment inputs from roads, such as when road runoff discharges into low-order channels that once would have provided clean inflows, and riparian roads that restrict access to flood-plain and off-channel refugia (Reid 1998). Coho salmon streams with the best over-wintering habitat are those with LWD accumulations, spring-fed ponds adjacent to the main channel, or protected and slow-flowing side channels that may only be wetted in winter. Backwaters and side channels that develop along unconstrained reaches in alluvial floodplains were historically important rearing habitats for juveniles (Sedell and Luchessa 1982).

In unstable coastal systems, coho salmon production may be limited by the lack of side channels and small tributaries to provide protection against winter floods. Beaver ponds can create additional habitat used by coho salmon, both in winter to avoid high flows, and in summer to avoid stranding as a result of low flows. Habitat complexity contributes to the creation of microhabitats within reaches, thus providing more opportunities for inter and intra-species stratification (Bjornn and Reiser 1991). Terrestrial insects and leaf drop falling into streams from riparian vegetation much of the food base for stream macroinvertebrates, which in turn are a major food source for juvenile coho salmon.

Emigration

Stream flow is important in facilitating the downstream migration of coho salmon smolts. Dorn (1989) found that increases in stream flow triggered downstream movement of coho salmon. Similarly, Spence (1995) also found short-term increases in stream flow to be an important stimulus for smolt emigration. Thus, the normal range of stream flow may be required to maintain normal temporal patterns of migration. In years with low flows, emigration is earlier. Artificial obstructions such as dams and diversions may impede emigration where they create unnatural hydraulic configurations or impediments.

Temperature affects emigration timing of coho salmon smolts by influencing their rate of growth and physiological development, and their responsiveness to other environmental stimuli (Groot 1982). Alteration of thermal regimes through land-use practices and dam operations can influence the timing of emigration. The probability that coho smolts will migrate downstream increases with rapid increases in temperature (Spence 1995). Holtby (1988) found that coho salmon smolts in British Columbia emigrated approximately eight days earlier in response to logging-induced increases in stream temperatures. In addition, the age-class distribution was shifted from populations evenly split between one- and two-year old smolts to populations dominated by one-year old fish. If the majority of smolts emigrate at the same age, poor ocean conditions could have a greater effect on that particular year class than if the risk was spread over two years. Coho salmon have been observed throughout their range to emigrate at temperatures ranging from 36.6°F up to as high as 55.9°F (Sandercock 1991). Coho salmon have been observed emigrating through the Klamath River estuary in mid-to late-May when water temperature ranged from 53.6 to 68°F (CDFG unpubl. data).

Supersaturation of dissolved gases (especially nitrogen) has been found to cause gas bubble disease in downstream migrating salmonids (Ebel and Raymond 1976). Emigrating fish are particularly vulnerable to predation (Larsson 1985). Physical structures in the form of undercut banks and LWD provide refugia during resting periods and cover from predators.

Essential Estuarine Habitat

Estuaries are essential habitat of Pacific salmon, including coho salmon (Sedell et al. 1991). Both adult and juvenile coho salmon utilize estuaries throughout their range in California. Adults use estuaries for staging as they prepare for their migration upstream. Juveniles use estuaries for rearing, and completion of smoltification. Juveniles may occupy estuaries for several weeks before migrating out to sea. In fact, the phenomenon of smolts migrating out is not a single, unidirectional event; smolts may move in and out of the estuary a few times before finally remaining in the marine environment.

Returning adults enter the freshwater environment through estuaries. Access to the estuaries, sufficient cover, and adequate flow and water quality, including temperature, are all important factors for these fish. Once in the estuaries, upstream migration generally is associated with high out flow combined with high tides (Sandercock 1991).

Young fish are very susceptible to predation once they reach the lower river system and estuary, where water quality and habitat complexity is a crucial factor in their ability to survive. Substrate habitat complexity and adequate woody debris are necessary for shelter and hiding, while a sufficient, invertebrate food source is necessary for continued growth and physiological development prior to leaving the estuary. These physical and biological conditions are related to the (1) type, diversity, distribution, and quality of substrate, (2) amount, timing and quality of freshwater discharge, and (3) tidal pattern and quality of marine waters. Estuaries provide important rearing habitat, especially in smaller coastal streams where freshwater rearing habitat is limited.

Summary of Essential Habitat

Coho salmon inhabit three aquatic environments during the course of their life cycle: freshwater streams, coastal estuaries, and the ocean. In each of these environments, particular ecological conditions are necessary for each coho salmon life-stage, as described in the preceding sections. Each condition has a broader range that allows for survival and a narrower range that represents the optimum for coho salmon health, as measured by activity, growth, resistance to disease, and other factors.

It should be noted that most studies define optimal conditions on the basis of physiological responses or efficiencies under laboratory conditions. If coho salmon populations are locally adapted to the particular suite of environmental conditions in their natal stream, then ecologically optimal conditions may fall outside of the narrow range deemed physiologically optimal. Most important of these potential influences is the alteration in timing of life-history events.

Table 3 identifies the major freshwater habitats used by each life-stage of coho salmon. Table 4 summarizes essential habitat elements and shows the range of suitability necessary for the viability and survival of coho salmon for each element. The following is a summary of these essential habitat elements that were discussed by life-stage in the preceding sections.

Table 3. Freshwater habitats of the different life-stages of northern California coho salmon.

Freshwater Habitat	Coho Salmon Life-Stage
Flat water-riffle	fry, juveniles, spawning adults
Flat water	juveniles, spawning adults
Gravel streambed	eggs, alevins, young fry, spawning adults
Pool	fry, juveniles, migrating adults
Side-channel	fry, juveniles
Stream bank	fry, juveniles
Submerged vegetation and LWD	juveniles

Stream Vegetation and Canopy Cover

Vegetation in the riparian corridor provides many benefits to stream conditions and habitat. The vegetation serves as a buffer from sediment and pollutant deposition in the watercourse. The riparian community as a whole also influences the geomorphology and stream flow of the channel. Vegetation adjacent to the water stabilizes the stream bank. Shade, provided by canopy, and the riparian buffer is vital to moderating water temperatures that influence spawning and rearing. The riparian canopy also serves as cover from predators, and supplies both insect prey and organic nutrients to streams.

Large Woody Debris

LWD is an essential component for several ecological functions. Within the estuarine environment, it stabilizes substrate, provides cover from predators, and provides shelter. In the freshwater environment, it serves these same functions as well as providing for pool establishment and maintenance, spawning bed integrity, habitat for aquatic invertebrate prey, and in-stream productivity.

Sediment and Substrate

The channel substrate type and size, and the quantity and distribution of sediment have important direct and indirect functions for several life-stages of coho salmon. Adults require gravel of appropriate size and shape for spawning, building redds, and laying eggs. Eggs develop and hatch within the substrate, and alevins remain there for some time for protection and shelter. The substrate also functions as habitat for rearing juveniles providing shelter from faster flowing water and protection from predators. Also, some invertebrate prey inhabit the benthic and epibenthic environment of the stream substrate habitat. An excess of fine sediment is a significant threat to eggs and fry because it can (1) reduce interstitial flow, which is necessary to regulate water temperature and DO, remove excreted waste, and provide food for fry, (2) reduce available habitat, and (3) encase, and then suffocate, eggs and fry. The flushing and cycling of fine sediments is paramount to coho salmon survival.

Hydrological Regime

The nature of the water properties (i.e. quality and quantity) and the characteristics of the stream channel are fundamental to all coho salmon life-stages that inhabit coastal watersheds. Some important characteristics include water temperature, water velocity, flow volume, and the seasonal changes and dynamics of each of these (e.g. summer maximum and mean temperature, summer flow, peak flow, winter storm surges).

Water Temperature

Water temperature is one of the most significant ecological elements for all life-stages of coho salmon. Water temperature is important to: the rate and success of egg development; fry maturation; juvenile growth, distribution, and survival; smoltification; initiation of adult migration; and survival and success of spawning adults. Water temperature is influenced by many factors including stream flow, riparian vegetation, channel morphology, hydrology, soil-geomorphology interaction, climate, and anthropogenic impacts. The heat contained within the water (stream thermal budget) and the ecological paths through which heat enters and leaves the water (heat transfer mechanisms) are dynamic and complex. There is also small- and large-scale heterogeneity based on stream depth, cross-section width, and flow (Essig 1998).

Water temperature requirements can be partitioned into important categories, each representing a temperature regime related to unique physiological phenomena. Three important complicating factors are important to note. First, environmental conditions in specific watersheds may effect the range and extreme end-points for any of these temperature categories for coho salmon within these watersheds. Second, water temperature requirements are dependent on fish metabolism and health, and available food. Third, individual coho salmon populations are adapted to habitat conditions within specific watersheds, therefore some populations may differ slightly in their temperature requirements and tolerances. These factors need to be considered together when trying to understand the habitat needs of coho salmon in a particular watershed or on a particular river system. Important water temperature regimes include:

- Optimum temperature: temperature that allows for optimum conditions for one or more activities (e.g. migration, spawning, foraging) or physiological process (e.g. growth, embryo or alevin development, fertilization) of any given life-stage of fish.

- Threshold temperature: temperature that inhibits a physiological process or behavior of a particular life-stage of fish (e.g. inhibits upstream migration or inhibits proper embryo development).

- Disease threshold: threshold where increased temperature results in an increased probability of mortality from warmwater- related diseases.

- Ultimate upper incipient lethal temperature: temperature that kills 50% of fish within a 24-hour period in a constant-temperature laboratory test after those test fish were acclimated to the highest temperature that allowed the maximum degree of thermal tolerance.

- Maximum weekly maximum temperature (MWMT): the highest daily temperature averaged over a seven day period. For fisheries biology, this a measurement used to understand presence/absence, stream and fish population productivity, physiological health or stress, mortality, and susceptibility to disease.

- Maximum weekly average temperature (MWAT): the highest mean temperature averaged over a seven day period. Like MWMT, this a measurement used to understand presence/absence, stream and fish population productivity, physiological health or stress, mortality, and susceptibility to disease.

Dissolved Oxygen

An adequate quantity of DO is necessary for each life-stage of coho salmon. DO is affected by water temperature, in-stream primary productivity, and stream flow. Also, fine sediment concentrations in gravel beds can affect the DO levels, impacting egg and fry.

Table 4. Fundamental habitat elements and suitable ranges for coho salmon life-stages.

Element	Life Stage	Suitable Range	Reference or Citation
Large woody debris	rearing juvenile	> 400f ^{3}/100f reach [a]	Murphy 1995
Riparian cover	rearing juvenile	$ 80%	Flosi et al. 1998
Sediment and substrate	spawning adult	20% fine sediment; .51-4.02 inches (size) [b]	Reiser and Bjornn 1979; Bjornn and Reiser 1991
	eggs and fry	depth: 7.01-15.41 inches; 0=9.85; diameter: 1.54-5.40, 0=3.70; < 20% fine; < 12% fine, < 5% fine (optimum)	Briggs 1953; Cederholm and Reid 1987; PFMC 1999
Stream flow (peak flow, storm surges, minimum summer flow)	migrating adult	*- discharge is specific to stream -*	
	spawning adult	*- discharge is specific to stream -*	
	rearing juvenile	*- discharge is specific to stream*	
Territory (square feet)	spawning pair	126f^2	Bjornn and Reiser 1991
	rearing juvenile	26-59/fish;0= .001-1.0 fish per 3.281 [.5-1 year old]	Reiser and Bjornn 1979; Bjornn and Reiser 1991

Table 4, continued

Element	Life Stage	Suitable Range	Reference or Citation
Turbidity (NTU [c])	migrating adult	< 30 ounces/gal[a]	Bjornn and Reiser 1991
	spawning adult	clear to heavily silted	Sandercock 1991
	juvenile	> 60 (disrupted behavior); > 70 (avoidance)	Bjornn and Reiser 1991
Water depth (inches)	migrating and spawning adult	4.02-7.88; 0=6.19; 7 (minimum)	Briggs 1953; Bjornn and Reiser 1991
	rearing juvenile [d]	9.46-48.07	Bjornn and Reiser 1991
Dissolved oxygen (ounces/gallon)	migrating adult	$80% saturation and > .037[1]	Bjornn and Reiser 1991
	rearing juvenile	100% saturation (preferred); .037-.044 stressed, > .059 (optimum)	Reiser and Bjornn 1979; Bjornn and Reiser 1991, PFMC 1999
	egg and fry	near saturation (preferred); > .059 (optimum)	Reiser and Bjornn 1979; Bjornn and Reiser 1991, PFMC 1999
Water temperature (EF)	migrating adult	44.6-59	Reiser and Bjornn 1979
	spawning adult	39.2-48.2	Bjornn and Reiser 1991
	rearing juvenile	35 (lower lethal), 78.8-83.8 (upper lethal), 53.6-57.2 (optimum); 48-59.9 (optimum); 63.7-64.9 (MWAT); 62.1 (MWAT) and 64.4 (MWMT)	Bjornn and Reiser 1991; Flosi et al. 1998; Ambrose et al. 1996, Ambrose and Hines 1997, 1998, Hines and Ambrose ND; Welsh et al. 2001
	eggs and fry	39.2-51.8; 39.2-55.4 (optimum); 32-62.6	Davidson and Hutchinson 1938; Bjornn and Reiser 1991, PFMC 1999; PFMC 1999
Water velocity (ft/s)	migrating adult	< 8	Reiser and Bjornn 1979
	spawning adult	.98-2.46; 1.02; 0=1.9, .98-2.99	Briggs 1953; Reiser and Bjornn 1979; Bjornn and Reiser 1991
	rearing juvenile	.30-.98 (preferred for age 0), 1.02-1.51 (riffle), .30-.79 (pool); .16-1.28[3]; .16-.98	Reiser and Bjornn 1979; Bjornn and Reiser 1991; PFMC 1999
	eggs and fry	.82-2.95	PFMC 1999

a Coho salmon research conducted in southeast Alaska.
b Estimated from other species or general for anadromous salmonids.
c NTU is nephelometric turbidity units
d Various sizes and ages. Fish either aged (0 and 1) or measured 15.8-24.4cm).

IV. HABITAT NECESSARY FOR SURVIVAL